veined by quartzo-felspathic material when near the granite. Typically they consist of abundant euhedral to subhedral green aluminous hornblende grains in a finely granular base of plagioclase (see Plate xi, B). The amphibole (X = pale yellow-brown, Y = brownish-green, Z = dark green; Z^c = 25°; α = 1·661, γ = 1·678) is distinctly different from the amphibole (actinolite) of the greenschists. Odd fragments of paler, more actinolitic amphibole may occur in the amphibolites but in at least some cases they are related to local retrogression. In the somewhat schistose amphibolites the amphibole porphyroblasts may be slightly rotated. Plagioclase in the amphibolites is granular, twinned, and is often remarkably clear. Large felspar areas (up to about 0·3 mm.) between the amphiboles resemble porphyroblasts but are usually aggregates of fine grains (smaller felspar porphyroblasts do, however, occur in a number of cases). The felspar is more calcic than that of the low-grade rocks and though oligoclase is the most usual type it may grade as far as andesine.

Quartz is of variable development; at times it is quite absent, whilst locally it may appear as an important accessory. Epidote-clinozoisite is not common in the amphibolites but rocks rich in this mineral do occur in this part of the belt. Frequently the epidote-rich rocks are obviously banded. The felspar associated with the epidote in such cases is usually very finely granular and untwinned but appears to be more calcic than albite. In general, there seems to be an inverse relation between the epidote minerals and hornblende in this locality (cf. Harker, 1939, p. 269). The reason for the appearance of epidote in the banded rocks is probably chemical, and chemical variations are also responsible, no doubt, for the rare occurrences of biotite (brown or green) and, even less commonly, of muscovite in a few of the rocks of the Greenbank area. The mica-bearing rocks must be richer in alkalis than are the normal amphibolites but this has not yet been confirmed by analysis. It is not clear whether these micaceous rocks are strictly of igneous parentage or whether they were derived from basic sediments intruded by or interbedded with the amphibolites.

One specimen of amphibolite has been analysed with the result given in Table 2 (no. 1). The most remarkable features are the rather low MgO and high CaO contents, whilst it is readily seen that in composition the rock approaches a basalt. It is a matter of no little interest to note that the rock is chemically close to certain amphibole-bearing granulites and amphibolites from the Cooma district. Joplin (1942) was struck by the distinctive composition of these latter rocks. Somewhat similar types have also been found at Albury. The Albury and Cooma examples were compared by Joplin (1947), but it can be seen that on an ACF diagram (Text-fig. 1) the former fall outside the field which Dr. Joplin drew to include the Cooma representatives of this group. On this diagram the analysed rock from the present area falls within the "Cooma" field. Other rocks plotted on this diagram include the "andesitic" type from Nangus (Table 1, no. 1). When calculated without regard for CO_2 it also appears within the enclosed field as does the "kersantite" from Adelong when treated in the same way.

Near the granite contact at George's Hill, about three miles west of Adelong, a few of the basic rocks are characterized by large (up to 6 mm.) crystals of amphibole, some of which, at least, are derived from pyroxene (+ve; Z^c = 44°). The amphibole is usually a pale green, feebly pleochroic type with extinction angles up to 24°. On occasions it may be recrystallized to aggregates of more strongly pleochroic hornblende like that in the normal amphibolites. Epidote and sphene are common in these rocks and oligoclase normally is associated with granular amphibole in the base. As amphibole and not pyroxene characterizes the metamorphosed basic rocks in this part of the belt it seems probable that the latter mineral, now partly replaced, is primary.

Pyroxene does, however, become a constituent of certain metamorphosed rocks further to the south, near the village of Sharp's Creek (about three miles west of Wondalga). These rocks are typically dark grey, fine-grained, compact granulites consisting of rhombic pyroxene, plagioclase, quartz, biotite, and magnetite. The pyroxene is grey in colour, non-pleochroic, optically negative (hypersthene), and occurs as small, ragged, sometimes poikiloblastic grains which occasionally form narrow bands or strings through the rocks. Plagioclase is granular, of variable size, the larger grains (about 0·4 mm.) often being rich in tiny quartz inclusions; it is only occasionally twinned. Its composition is more calcic than that of the felspar of the amphibolites and ranges down to labradorite (Ab_{40}). Strongly pleochroic biotite (X = straw yellow, Y = red-brown, Z = dark red-brown) flakes are less common but still widespread.

This mineral association hypersthene-labradorite (probably indicative of Pyroxene Hornfels Facies metamorphism; evidence of Granulite Facies conditions is quite lacking in this area) in strongly recrystallized rocks has not been found extensively, in fact it seems to be represented only on the western side of the basic belt in this more

TABLE 2.

	1	A	B	C	D	E
SiO_2	48·41	49·50	48·23	48·76	49·07	47·24
Al_2O_3	16·78	16·47	16·67	14·96	21·76	18·55
Fe_2O_3 ..	2·90	0·72	2·60	1·91	3·44	6·02
FeO	9·03	9·10	6·09	6·75	8·74	4·06
MgO	5·35	7·47	7·65	7·34	3·65	5·24
CaO	13·33	14·79	9·22	10·00	10·32	11·72
Na_2O	1·89	0·47	1·67	1·03	1·03	2·42
K_2O	0·47	0·32	0·84	0·95	0·37	0·15
H_2O+	0·44	0·57	3·17	2·97	0·62	2·24
H_2O-	0·27	0·03	0·25	0·35	0·14	0·21
TiO_2	1·19	0·75	0·78	0·65	0·69	1·46
P_2O_5	n.d.	0·05	0·26	0·13	tr.	0·26
MnO	0·32	0·16	0·15	0·17	n.d.	0·31
CO_2	—	—	1·88	3·40	—	0·19
Etc.	—	—	—	1·09	—	0·05
	100·38	100·40	99·52	100·46	99·83	100·12

1. Amphibolite. Top of George's Hill, Por. 58, Par. of Ellerslie, Co. Wynyard. Anal. T. G. Vallance.

A. Hornblende granulite (with trace of pyroxene). Cooma area. Anal. G. A. Joplin. PROC. LINN. SOC. N.S.W., 67, 1942, p. 172.

B. Altered basic rock. Albury area. Anal. G. A. Joplin. *Ibid.*, 72, 1947, p. 90.

C. "Trachytic rock." Hume Reservoir (Albury area). Anal. W. A. Greig. *Ann. Rept. Dept. Mines N.S.W.*, 1924, p. 105.

D. "Amphibolite" xenolith. Murrumbucca Creek at Gap Road crossing (Cooma area). Anal. G. A. Joplin. Unpublished analysis by courtesy of the analyst.

E. Basalt (porphyritic central type). Mull, Scotland. Anal. E. G. Radley. *Mem. Geol. Surv. Scotland*, "Mull", 1924, p. 24. (Called porphyritic basic augite andesite lava in *Summ. Progress* for 1915, p. 26.)

southerly part of its outcrop and even there it is not very widespread. It is interesting to note that the apparent facies progression from Amphibolite Facies to Pyroxene Hornfels Facies takes place in rocks which are all roughly in equivalent positions relative to the Ellerslie granite. Normal pelites do not occur near this part of the belt, but the suggestion is made that these pyroxenic rocks and the amphibolites are more or less isogradal with the high-grade and knotted-schist-zone metasediments.

(*b*) *Rocks of Doubtful Metamorphic Status.*

The greater part of the belt from near Adelong to Batlow consists of amphibole- and, in some cases, pyroxene-bearing rocks which are usually coarser (fine-medium grain size) than the types discussed in the preceding section and are of somewhat doubtful metamorphic status. Most of them probably ante-date the Ellerslie and Wondalga granites, but frequently their textural aspect is more like that of an igneous rock than one which has suffered much metamorphism. Amongst the members of this group a certain amount of diversity with regard to mineral content and texture exists.

Hypersthene-labradorite rocks (these are quite different from the pyroxene-granulites mentioned above) characterized by laths of twinned felspar and subhedral pleochroic (pink to grey-green) hypersthene have been found to the east of Adelong Creek in the southern part of the Parish of Adelong and further to the west near the Sharp's Creek road. Olivine has not been encountered in these rocks which otherwise are similar to certain finer-grained phases of the Adelong norite. A feature of these rocks is the presence of ragged grains of magnetite of apparently late crystallization. Pleochroic green hornblende is sometimes moulded on to the pyroxene. Brown biotite flakes are not uncommon. The relation of these rocks to the following has not been established, but as they all occur in the same belt they are considered together here.

Many of the intermediate to basic rocks display evidence of progressive mineralogical changes with the development of minerals such as green hornblende and, in places, actinolite at the expense of pyroxene and brown hornblende. All gradations are found from rocks typically carrying the former minerals to those with pyroxene and/or brown hornblende which may retain an "igneous" appearance. In addition to being directly derived from pre-existing pyroxene or amphibole the green hornblende also occurs as needles and blades in the base of such rocks. Rarely the amphibole of the base may be granular. Rocks particularly rich in fibrous tremolite-actinolite are locally found in shear-zones; a good example occurs near the southern boundary of the Parish of Adelong on the Adelong-Wondalga road.

Colourless pyroxene, somewhat granular or in prismatic crystals, is often less altered to green amphibole than is the accompanying brown hornblende. The pyroxene (+ve; $Z\wedge c = 43°$) is a diopsidic augite. Granular clinozoisite occurs with it in places. Most of the rocks of this group carry felspar, about andesine in composition. Twinning is common and irregular extinction features due to strain or even actual ruptures may occur, particularly in the larger grains. In general, the felspar of these basic dioritic rocks is quite fresh, but occasionally it may be replaced by albite—perhaps as a result of deuteric alteration. The albite-bearing rocks are not widespread. Of the accessories in the rocks of this whole group the most important are apatite, sphene, and magnetite; quartz rarely plays more than an accessory rôle.

Near the top of the ridge on the Sharp's Creek road a few rocks are marked by the presence of large (up to 10 mm.) euhedral pyroxene crystals, sometimes rendered patchy by partial alteration to amphibole, set in a granular matrix consisting essentially of pyroxene, green-brown hornblende, andesine-labradorite, brown biotite, and iron-ore. The pyroxene of the large crystals is augitic, whilst hypersthene is represented in the base. Rhombic pyroxene has, in places, grown on the margins of the augite (Plate xi, C), but elsewhere the clinopyroxene may have an amphibole-mantle. The reason for these apparent anomalies is not clear, but the presence of hypersthene mantles might suggest a metamorphic origin. Diopside grains fringed with granular hypersthene occur in certain basic charnockites in Sweden (Quensel, 1951) as well as in India and Uganda. In such cases the reaction diopside $\rightarrow$ hypersthene is almost certainly related to the deep-seated plutonic environment in which the charnockites were formed. It might be argued that the Sharp's Creek road rock has suffered a metamorphism of the type which affected the pyroxene granulite (see p. 185) about one and a half miles away, but there is not much evidence upon which to establish this. Late hypersthene associated with hornblende and biotite also occurs in the Adelong norite-gabbro (in the latter the hypersthene crystallized over a considerable period relative to the clinopyroxene), a rock which does not appear to have suffered much metamorphism. This introduces a doubt as to whether the rock under discussion owes its appearance today to metamorphic recrystallization or to an unusual type of primary igneous crystallization; at present no really satisfactory answer suggests itself. Wilson (1952) records hypersthene of metasomatic origin replacing and mantling clinopyroxene and associated with biotite, but there is little evidence to support the view that the hypersthene in the present case is metasomatic.

Two relatively small masses of dioritic-gabbroic rocks, in many respects similar to the aforementioned basic diorites, occur in the neighbourhood of Bangandang Trig. Station. One of these masses is enclosed by the Ellerslie granite, and the second, roughly in the line of strike of the belt, invades low-grade metasediments. Poor exposures are typical of the contacts of both of these masses; the second does not seem to have had much thermal effect on the metasediments.

The rocks of these two masses are more or less massive with a dark colour and medium grain size and consist mainly of amphibole and plagioclase. The zoned plagioclase crystals (andesine-labradorite) often have epidotized cores. The average grain size of the felspar in the more northerly mass is distinctly less than that of the large hornblende crystals (3-4 mm.). The grain size is more uniform in the mass enclosed by the granite. Interstitial quartz (sometimes in graphic intergrowth with felspar) is a rare accessory; other accessories are apatite, sphene, and iron-ore. Small relict patches of pyroxene (both rhombic and monoclinic, but mainly the latter) fringed by brown hornblende (pleochroic from pale straw to dark brown; $Z^\wedge c = 26°$) occur in some cases. Brown hornblende also appears as well-formed crystals and grains mantled by green hornblende (X = pale yellow-green, Y = medium yellow-green, Z = bluish-green). Some of the brown hornblende patches have a subophitic aspect. Pale green fibrous actinolite is not uncommon; frequently it grows on the margins of the green hornblende. The series pyroxene → brown hornblende → green hornblende → actinolite (uralite) may be regarded (see Erdmannsdörffer, 1947; Nickel, 1952) as a normal scheme associated with the cooling of dioritic or gabbroic magmas, although similar mineral changes could conceivably be brought about by metamorphic agencies (cf. the concept of magmatic-metamorphic convergence; see Erdmannsdörffer, 1948). Brown hornblende may develop in certain metamorphosed basic rocks in proximity to plutonic masses (Egeler, 1947; Deer, 1953), but, as Eskola (1939) has said, "der braunen Hornblenden höherer Temperaturbereiche der Magmagesteine und der gemeinen grünen Hornblenden, wie sie charakterischerweise in den Gesteinen der Amphibolitfazies und noch in manchen Epidotamphiboliten". In the present case the brown hornblende occurs both near to and away from the Ellerslie granite mass and the area of true amphibolites; there can be little doubt that the mineral is primary and magmatic. Similar green hornblende also occurs in the two masses, one of which, as was said, is remote from the higher-grade part of the region, and it is reasonable to expect that it, too, may have been part of a magmatic reaction series associated with cooling (probably the same is true of the hornblendes in the basic diorites of the "basic belt"). When we come to the actinolitic amphibole there is not sufficient clear evidence to prove definitely whether it belongs strictly to this cooling series or whether it is related to some later low-grade metamorphism. Although the rocks are apparently massive, their felspar often shows signs of fracture which may have been related to some period of low-grade metamorphic activity.

The difficulty in assessing the extent of the metamorphism which affected these rocks, together with the rest of the members of this group, is the reason for their being discussed under the heading "of doubtful metamorphic status". In many cases it seems that the metamorphism (*sensu stricto*), if any, which affected them was not intense.

(*c*) *Concluding Remarks.*

To conclude, it is suggested that there are two main groups of basic rocks in the southern part of the belt. The first includes the granulitic green hornblende-plagioclase rocks (amphibolites) and hypersthene-plagioclase granulites. Associated with these, near Greenbank, are some epidote- and biotite-bearing banded rocks which may be of sedimentary origin. Rocks at Cooma, chemically similar to the amphibolites here, were thought by Joplin (1942, p. 173) to represent contemporaneous flows or small sills among the Ordovician metasediments. In the present case their real nature has not been established. The metamorphism which left its mark on these rocks was not strictly related to the Ellerslie granite because the metamorphic grade appears to increase to the south; it is clear from field evidence, however, that these basic rocks ante-dated this granite. The second group includes rocks of greater diversity. Texturally they are usually coarser than the above-mentioned types and often have an "igneous" appearance. The second-group rocks frequently display signs of the mineral series pyroxene–brown hornblende–green hornblende–actinolite; a sequence apparent in both massive and somewhat deformed types. In some cases the series seems to be due to progressive changes in the cooling environment of these rocks during their magmatic stage; there may, however, be an overlap between such a process and rather low-grade metamorphic activity. The second-group rocks in general also ante-date the Ellerslie-Wondalga granite but they have come later than the members of the first group. The relatively coarse nature of the later rocks, and the apparent scope for reaction of pyroxene with residual magmatic material to give hornblende, etc., rims suggest a rather long cooling period probably more in keeping with an intrusive environment than with the rocks being extrusive.

Two possibilities suggest themselves as reasons for the development of metamorphic pyroxene in the granulites and for the general increase in metamorphic grade in the greenschists and first-group rocks towards the south. They are that the effects are due largely (1) to the thermal influence of the second-group basic rocks on the earlier types or (2) to the metamorphism with which the Green Hills granite mass was associated (it will be remembered that this granite was linked with the highest-grade metamorphism of the metasediments—see Vallance, 1953). The increase in grade in the metamorphosed basic rocks occurs with approach to this granite but it is also in this part of the belt that the second-group basic rocks are most common. The patchy development of the pyroxene granulites might suggest local thermal action by the later basic rocks (pyroxenic rocks, in many respects similar to the granulites here, occur locally in Scotland as high-grade contact-metamorphosed products derived from Tertiary igneous rocks—see MacGregor, 1931). It should be noted, however, that such granulites are typically formed on the western side of the belt, i.e. nearest the Green Hills mass. As none of the basic rocks are found in contact with this granite no definite age-relations can be established with it. At Cooma (Joplin, 1942), the granulites, similar to the amphibolites here (see p. 185), occur as inclusions in the Cooma gneiss which is closely comparable with the Green Hills granite. No basic inclusions have been found in the latter, but if the lithological correlation with Cooma is valid and has age significance then the amphibolites here may ante-date the Green Hills granite. Whether the second-group basic rocks ante-date or post-date this granite is not really known. As these second-group basic rocks do not appear, as a rule, to have suffered the general metamorphism which affected certain greenschists as well as the amphibolites and metasediments, they may post-date the Green Hills, for that granite seems to be closely associated with the general metamorphism.

"Kersantites."

Of doubtful relation to the other basic rocks are the small bodies, regarded by Harper (1916) as dykes, in the granite at Adelong. They were called kersantites by Card, but the diagnosis must have been based primarily on chemical composition. No opportunity was available to examine these rocks in the field because they appear to be commonly recognized only in the underground workings of the old gold-mines. These mines are not being worked at the present day. However, a fairly representative collection of these rocks, assembled by Harper, is housed in the Mining Museum, Sydney, and was kindly made available for study.

In the following brief remarks mention will be made of the mineralogy of these rocks, although little can be added to Harper's statement on their field occurrence. Harper refers to dykes of different ages, only the earlier group of which has suffered dynamic action. Both schistose and massive varieties are in the Mining Museum collection, but all are alike in showing extensive recrystallization. Both types often have comparable mineralogical constitutions, most commonly consisting of muscovite, biotite, quartz, calcite, felspar, with chlorite, epidote, amphibole, sphene, and pyrite on occasions. The rocks display few lamprophyric characters.

The schistose types commonly carry two micas and calcite but variations in composition are reflected in the development of pale green or blue-green pleochroic amphibole (X = very pale yellow, Y = pale yellow-green, Z = mid-bluish-green; $Z \wedge c = 21°$) in a few cases. Most of the ferromagnesian minerals tend to form clots which, in the schistose rocks, are elongated along the schistosity. Biotite flakes (X = pale yellow-brown, Y = mid-greenish-brown, Z = very dark brown or greenish-brown) may grow either across or along the schistosity. Occasionally biotite becomes the major component in these rocks. Twinned calcite grains (up to 1 mm. in the coarser types) are widespread and their presence distinguishes the two-mica schists here from the pelitic schists described in Part I of these studies. The felspar, where determined, appears to be oligoclase or albite, more commonly the latter.

TABLE 3.

	1	A	B	C
SiO_2	49·66	53·04	47·79	50·76
Al_2O_3	17·44	15·68	18·23	12·20
Fe_2O_3	1·00	4·25	2·76	1·19
FeO	6·75	4·41	9·18	6·65
MgO	4·71	5·79	5·23	11·75
CaO	7·10	6·02	6·32	6·26
Na_2O	2·69	3·28	2·66	2·16
K_2O	3·85	3·10	4·10	4·79
H_2O+	1·53	2·49	2·15	0·66
H_2O-	0·09		0·08	0·22
TiO_2	1·22	0·73	1·35	0·76
P_2O_5	0·22	0·30	0·42	0·28
MnO	0·11	—	0·20	0·30
CO_2	3·00	0·88	0·0	1·39
Etc.	0·59	0·14	0·21	0·41
	99·96	100·11	100·68	99·78

1. Kersantite. Gibraltar Mine, Adelong. Anal. W. A. Greig. *Ann. Rept. Dept. Mines N.S.W.*, 1916, p. 225.

A. Average of 54 rocks called kersantites. Quoted from Johannsen (1937), vol. III, p. 190.

B. Biotitplagioklasschiefer. Seidenbuch (Odenwald). Anal. Hartwig. In Erdmannsdörffer, *Heidelberger Beit. Min. Pet.*, 1, 1947, p. 66.

C. Biotite-hornblende-schist (lamproschist). 1 mile S.E. of Glencalvie Lodge, Ross & Cromarty, Scotland. Anal. E. G. Radley. *Mem. Geol. Surv. Scotland*, 1912, " Ben Wyvis, Carn Chuinneag, Inchbae and the surrounding country ", p. 125.

As far as mineral assemblages indicate, both massive and schistose varieties seem to have suffered fairly comparable degrees of metamorphism, at least equal to the biotite-chlorite subfacies of the Greenschist Facies, although they might belong to the Epidote-Albite Amphibolite Facies (Turner, 1948). The presence of these assemblages in rocks which are supposed to intrude and thus post-date the granite (Wondalga granite) suggests that there was some post-granite metamorphism. Even the massive types show few signs of relict igneous textures although they have not suffered any dynamic action. In view of the present inaccessibility of these rocks the problem of why the massive types should have a mineralogy similar to that of the schistose varieties cannot be solved. Perhaps here again late-magmatic and dynamothermal metamorphic effects were convergent as far as the development of new mineral phases was concerned.

The chemical composition of the analysed rock (Table 3, no. 1) is comparable with that of a kersantite. The rock is plotted on an ACF diagram (Text-fig. 1, points no. 15) both with and without regard to CO_2. The two points obtained are joined in the diagram. From the diagram it can be seen that the "kersantite" is not far removed from the amphibolites (it should be noted, however, that the latter ante-date the Wondalga granite whilst, according to Harper, the "kersantites" post-date it). The remarkably high potash content of the "kersantite" is reflected in the large amounts of mica usually present. A schistose rock, from the Odenwald, with a somewhat similar composition and consisting essentially of biotite and plagioclase is quoted in Table 3 for comparison. Dynamothermally metamorphosed lamprophyres have been described from various parts of Scotland (Peach et al., 1912; Harker, 1939) and some of them have mineral assemblages comparable with the Adelong "kersantites".

The Adelong Norite–Gabbro.

Practically confined to the town area at Adelong is a small mass (about $1 \times \frac{1}{2}$ mile), elongated roughly north-west–south-east, composed of medium-grained basic rocks referred to as gabbros by Harper (1916). These rocks occupy a low area and their outcrop is variable. In places (particularly near the south-eastern margin of the mass) they appear as tors, but elsewhere isolated boulders and soil-type differences are the only clues available in delimiting the extent of the basic mass in the dominantly granitic terrain. Adelong Creek flows round the eastern side of the mass which has apparently controlled the course of the stream. At the south-eastern end of the mass a small quarry has been opened to exploit the rock for monumental purposes.

The rock is holocrystalline and, though obviously rich in plagioclase, where fresh has a distinctly dark colour. Altered patches are greenish; this alteration is in most cases related to zones of dislocation and is not merely due to atmospheric effects. In the fresh material long laths of clear plagioclase often display a preferred orientation; dark pyroxene crystals are usually also visible macroscopically. Coarse and irregular patches, with felspars up to one inch long, obvious brown hornblende and biotite in addition to pyroxene, are randomly distributed through the mass. Basic clots enriched in olivine and pyroxene, often to the exclusion of felspar, are also present in places. Mineralogically these latter clots appear to be closely related to their host rocks and may merely represent fragments of an early phase of the norite-gabbro.

The mode of a fairly typical specimen of the rock is given in Table 4. Plagioclase is abundant in all these rocks as twinned (albite, pericline, and carlsbad laws mainly) labradorite (Ab_{46}) laths remarkably free from inclusions. A few tiny olivine grains may be included, but equally often the felspar is included in the olivine. The laths display intricate undulose extinction patterns and often have small-scale ruptures. When bent, transverse cracks appear in the laths and these cracks may be filled by later felspar. Subhedral to anhedral olivine may be found in all stages of alteration to serpentine but in the fresh rocks it is largely unaltered. Magnetite inclusions, either as bands of fine granules or as larger skeletal aggregates, are a feature of much of the olivine. The olivine grains are sometimes mantled by brown hornblende or biotite but the mantles are irregular and rarely complete.

Two pyroxenes are typical but their relative proportions vary a good deal; as a result the rocks range in composition from olivine-augite norites to olivine-hypersthene gabbros. Rhombic pyroxene invariably occurs as pleochroic (X = bright pink, Y = straw, Z = pale yellow-green) subhedral or anhedral grains. Optically negative, the grains occasionally exhibit oblique extinction (up to 16°—cf. Johannsen, 1937, vol. III, p. 212). Fine schiller inclusions may occur in this mineral but they are never as abundant as in the clinopyroxene. The latter commonly is polysynthetically twinned and has typical pyroxene cleavages. The grains are greyish, non-pleochroic, optically positive, and have $Z \wedge c$ up to 49°, corresponding to augite. The schiller inclusions produce a dirty brown coloration whilst local alteration to amphibole gives rise to patchy extinction effects in the pyroxene.

The four minerals labradorite, hypersthene, augite, and olivine constitute the main part of the mass but locally, as was mentioned above, patches with more complex mineralogy occur. In column 2 of Table 4 it will be seen that practically all the members of Bowen's well-known reaction series may be present in such cases. Olivine is typically less abundant in these more acid phases and may actually be absent. Augite and hypersthene occur and are often partly mantled by hornblende; patches of brown amphibole may appear in the augite. Separate hornblende (Z^c up to 29°) grains at times have ophitic relations to the felspar laths. In general, there is a colour zoning from brown-green to green or blue-green from the interior to the margins of the hornblende grains. Large plates of brownish biotite (X = pale straw yellow, Y = dark brown or greenish-brown, Z = dark brown to greenish-brown) up to 3–4 mm. across may also occur with the hornblende. A distinctly different biotite (X = pale straw yellow, Y = bright leaf-green, X = dark leaf-green; –ve; 2V very small) occasionally mantles pyroxene grains but is much less important than the brown variety. The latter type may have inclusions of calcite along the cleavages. Sometimes biotite appears to grow on hornblende which has itself grown on pyroxene. Muscovite is a rare accessory. Quartz is also rare (the 0·7% of quartz in the mode quoted is rather exceptional).

TABLE 4.

Modes of Rocks in the Adelong Norite-Gabbro Mass.

	1	2
Quartz	—	0·7
Labradorite	58·3	41·0
Apatite	0·1	0·1
Biotite (brown)	0·1	8·5
(green)	—	0·6
Hornblende	0·2	15·5
Hypersthene	18·2	10·2
Augite	8·7	14·0
Olivine	12·1	2·1
Magnetite	2·1	1·0
Muscovite..	—	tr.
Actinolite	—	5·5
Serpentine	tr.	0·4
	99·8	99·6

1. Olivine-augite norite.
2. Quartz- and olivine-bearing biotite-hornblende-hypersthene gabbro.

Pale green actinolitic amphibole may appear as an alteration product of the pyroxene or hornblende. Locally, in zones of dislocation, the reaction is carried to extremes. Even structurally unaltered rocks from the vicinity of the crush bands may show signs of this change. The actinolite (X = very pale yellow-green, Y = yellow-green, Z = mid-green or blue-green; Z^c = 18°) occurs both as needles and as uralitic patches directly replacing the earlier ferromagnesian minerals. Chlorite sometimes appears with the actinolite. In view of the field association there can be little doubt that the green actinolite-rich rocks developed from the norite-gabbro by localized low-grade dynamic metamorphism.

Whilst the actinolite may be explained away as being of metamorphic origin such was probably not the case with the green and brown hornblendes and biotites in the patches already described. These latter minerals may mantle the pyroxenes and olivine and appear to have formed later than these, though still probably during the magmatic period. Of the pyroxenes, hypersthene appears to have finished crystallizing last (it sometimes mantles augite, cf. p. 187), but as it also occurs as inclusions in the augite it probably had a lengthy crystallization period. Plagioclase must have separated at an early stage and it is interesting to note that whereas the plagioclase twins are often twisted and even ruptured, such features are very rarely displayed by the twins in the pyroxene grains. Perhaps the development of rhombic pyroxene in the norite and gabbro was related to the early crystallization of plagioclase. Olivine also was of early formation and was followed by the two pyroxenes, hornblende, and finally biotite. The most reasonable explanation for this sequence seems to be given in terms of the reaction series, with the hornblende and biotite mantling pyroxene and olivine being in the nature of reaction rims (Bowen, 1928). The presence of accessory quartz in the more acid, coarser patches adds plausibility to this explanation based on progressive changes in environment leading to differentiation during consolidation of the magma.

TABLE 5.

	1	A	B	C
SiO_2	52·54	50·04	55·05	57·18
Al_2O_3	16·94	18·68	14·15	14·13
Fe_2O_3	2·10	0·80	1·80	1·90
FeO	4·77	6·91	5·31	5·85
MgO	9·05	7·79	8·07	7·00
CaO	10·44	9·88	9·36	7·64
Na_2O	2·92	2·35	2·82	2·36
K_2O	0·44	0·12	0·72	2·30
H_2O+	0·45	1·74	1·46	0·45
H_2O-	0·07	0·28	0·22	0·07
TiO_2	0·40	0·80	0·57	0·60
P_2O_5	0·04	0·16	0·06	0·21
MnO	0·12	0·14	0·22	0·11
CO_2	0·11	0·27	0·02	abs.
Etc.	tr.	0·62	0·06	0·22
	100·39	100·58	99·89	100·02

1. Norite. Adelong village. Anal. H. P. White. *Ann. Rept. Dept. Mines N.S.W.*, 1916, p. 225.

A. Diorite. Murgatroyd's Tunnel, Hillgrove area, N.S.W. Anal. J. C. H. Mingaye. *Geol. Surv. N.S.W., Records*, 8, 1907, p. 216.

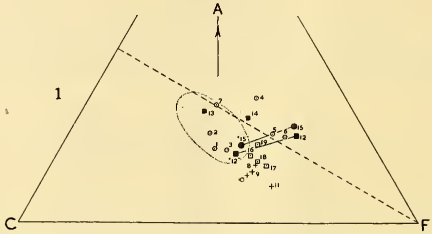
B. Diorite. Hillgrove area. Anal. J. C. H. Mingaye. *Ibid.*, p. 214.

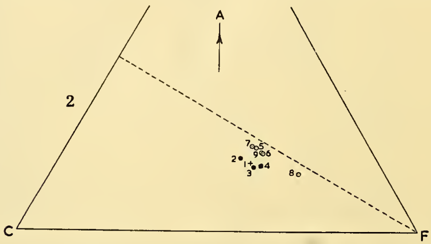
C. Quartz monzonite. Kiandra, N.S.W. Anal. W. A. Greig. *Jour. Proc. Roy. Soc. N.S.W.*, 56, 1923, p. 269.

In 1923 Browne and Greig described from Kiandra (about 45 miles south-east of Adelong) an olivine-bearing quartz monzonite which displays several features in common with the Adelong norite-gabbro. The sequence olivine, rhombic pyroxene, clinopyroxene, hornblende, and biotite is observed in both places. The clinohypersthene reported from Kiandra has not been found at Adelong, although hypersthene with apparent oblique extinction due to the chance orientation of thin sections has been noted in this study (p. 191). Potash felspar was not found in the Adelong basic rocks.

The Adelong norite-gabbro is surrounded by granite related to the Wondalga mass and the only age relations we have are with that granite. Harper (1916) stated that the basic rock "intrudes the granite, for round its edges wherever bedrock is exposed, tongues of gabbro, varying in width from a few feet up to many yards, are seen to be extending into the granite". In view of the freshness of the norite and the crumbly nature of much of the granite (due in large measure to cataclasis) this age relation might be expected but, in actual fact, as far as I have determined, the opposite state of affairs exists. Examination of the contacts (where exposed) west of the town suggests that the granite has actually invaded the norite and that the "tongues" of basic rock are really relics of the original mass. Fine granitic veins and very local felspathization of the norite indicate that the granite post-dates it. The granite seems merely to have proved more susceptible to the dynamic action than did the norite-gabbro. Little thermal effect on the basic rock appears to have been caused by the granite but, in view of the rather restricted contact features associated with this granite-type elsewhere, this is not really surprising.

It is interesting to note that Watt (1899), at Wyalong, found norite, somewhat similar to the Adelong rock, ante-dating a gneissic "granite" which, though more basic, is in many respects like the granite of the Ellerslie and Wondalga masses. Although Wyalong is about 100 miles north-west of Adelong, it lies on the same line of strike and the rock-associations in the two places may be more than accidental.





Text-fig. 1.—Point 1, This paper, Table 2, no. 1. 2, Joplin (1942), Table 6, no. II. 3, Joplin (1942), Table 6, no. I. 4, Joplin (1947), Table 4, No. I. 5, Joplin (1947), Table 4, no. II. 6, A.R.D.M. for 1924, p. 105, no. 1065/24. 7, This paper, Table 2, no. D. 8, 9, 10, 11, Cooma amphibolites, Joplin (1939). 12, This paper, Table 1, no. 1. 13, This paper, Table 1, no. B. 14, This paper, Table 1, no. A. 15, This paper, Table 3, no. 1. 16, This paper, Table V, no. 1. 17, This paper, Table I, no. C. 18, This paper, Table 5, no. A. 19, This paper, Table 5, no. B. (The enclosed field is taken from Joplin (1942), Fig. 5.)

Text-fig. 2.—Point 1, This paper, Table 5, no. 1. 2-4, Johannsen (1937), vol. III, Table 79 (average olivine gabbros). 5-9, Johannsen (1937), vol. III, Table 80 (average norites and olivine norites).

In Table 5 an analysis of the Adelong norite is quoted. The Hillgrove rocks noted for comparison are of interest because they are associated with gneissic granite chemically and lithologically similar to the granite at Adelong. Certain amphibolites at Cooma (Joplin, 1939) have the composition of gabbros or norites but any correlation between these and the Adelong norite-gabbro cannot be more than highly speculative. In Text-figure 1 it can be seen that the Adelong norite falls near the Cooma amphibolites. At Cooma these rocks ante-date the Cooma gneiss, which is, I believe, equivalent to the Green Hills granite in this area. It is thought that the Green Hills is itself older than the Ellerslie and Wondalga granites. However, if the basic rock ante-dated the Green Hills granite it should have suffered the general metamorphism; of this there is little indication. In David (1950) the norites of Adelong and Wyalong are tentatively referred to the late Silurian (Bowning) orogeny.

Chemically, the only analysed specimen from the Adelong basic mass is more closely allied to gabbros than to norites. In Text-figure 2 it will be seen that average norites and olivine norites tend to group themselves away from average olivine gabbros and that the Adelong rock falls with the gabbro group.

No definite statement is possible at present concerning the origin of the Adelong norite-gabbro. If the distinctive features are related to contamination of a basic magma by aluminous sediments (Bowen, 1928; Read, 1931) all trace of it has disappeared. There is thus no clear evidence upon which to decide whether the rocks were formed by the addition of aluminous material to a basic magma or by direct crystallization (without contamination) from a magma of the appropriate composition. Certain basic masses in various parts of the world have, in recent years, been regarded as representing "fronts" related to processes of granitization. However, in the present case insufficient evidence of large-scale and intense granitization which would have been necessary to produce the basic mass is available. Until this is definitely established, it seems preferable to continue to regard the norite-gabbro as having been magmatic and intrusive.

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EXPLANATION OF PLATE XI.

A.—Greenschist from Por. 157, Par. of Ellerslie. A fine-grained rock consisting mainly of actinolite, epidote, and albite. Much of the actinolite is arranged parallel to the obvious schistosity which is further accentuated by iron-staining. Ordinary light. × 13.

B.—A granular amphibolite from near the granite contact at George's Hill (Por. 58, Par. of Ellerslie). Obvious green hornblende is set in a base of clear plagioclase. A little epidote is present. Note the vague traces of banding and the occasional hornblende porphyroblasts in this specimen. Ordinary light. × 13.

C.—Granular basic rock from the western side of the "basic belt" on the Sharp's Creek road (Por. 67, Par. of Nacka Nacka). Large clinopyroxene grains (sometimes patchy due to partial alteration to amphibole) may have discontinuous rims of rhombic pyroxene. Granular rhombic pyroxene and plagioclase occur in the base with some clinopyroxene, hornblende and biotite. Ordinary light. × 13.

All photomicrographs by Mr. G. E. McInnes.

STUDIES IN THE METAMORPHIC AND PLUTONIC GEOLOGY OF THE WANTABADGERY–ADELONG–TUMBARUMBA DISTRICT, N.S.W.

Part III. The Granitic Rocks.

By T. G. Vallance, Linnean Macleay Fellow in Geology.

(Plate xii; ten Text-figures.)

[Read 30th September, 1953.]

Synopsis.

The plutonic rocks of this area are divided into three main groups. Representatives of two of these groups are here discussed in some detail. The earlier of the two is related to the period during which the essentially miogeosynclinal sediments were metamorphosed (see Vallance, 1953*a*). It is suggested that these granites were not formed in their present environment but have been derived (whether by anatexis or syntexis) from a deeper level, not yet exposed, of the metamorphic complex. Sedimentary material seems to have contributed a good deal to their formation. The second-group granites post-date the metamorphism but show interesting local reaction features with basic rocks. The rocks of these two groups are correlated with similar types at Cooma and elsewhere in New South Wales.

Introduction.

Granitic rocks of various types occupy a considerable part of the area examined and display many interesting relations to the rocks amongst which they occur. It is the purpose of this paper to describe these plutonic rocks and to discuss their relations to the metamorphism which affected the region.

On a lithological basis, the rocks have been separated into three groups. We shall be concerned with only two of these. Not much attention has been given to the third, designated here the Kyeamba adamellite; it occurs on the western side of the area and only a very small part of the mass has been mapped. More of it has been covered by Whiting (1950). Where examined, the rock is a massive, medium-grained, hornblende-free type which appears to be in a different metamorphic environment from the members of the other two plutonic groups; it is thought to be younger than these.

Of the other granitic groups, the members of the first are characterized by a medium grainsize, fairly massive appearance (some are slightly gneissic), roughly euhedral biotite flakes and a general absence of hornblende. Rocks of the second group also contain biotite as the chief melanocratic mineral but may, at times, carry amphibole as well. They may be somewhat coarser grained than the first group rocks and are often rather gneissic, sometimes markedly so. In general, the areas of highest grade metamorphism are associated with the first-group granites rather than with the second. Although both groups include types ranging from granite to granodiorite, it is usually not very difficult to separate them in the field. At Cooma, where metamorphism similar to that observed here has also left its mark, two main types of plutonic rocks occur and they are similar to those distinguished in this paper.

Granites of the First Group.

By way of introduction it should be made clear that the term granite will often be used here in a broad sense to include granodiorite. To the first group have been assigned the rocks of two large plutonic bodies, the Wantabadgery and the Green Hills (named after the Green Hills State Forest, which is largely situated on this rock type) masses.

The Wantabadgery granite occupies the south-eastern end of a large batholith which, according to the Geological Map of the State, extends to the north-west to near Methul West (about 16 miles south-east of Ardlethan). The batholith is depicted as having an irregular outline, yet with a distinct elongation parallel to the strike of the metasediments. The dimensions of the mass as marked on this map are about 60 × 25 miles. Whether the mass is uniform throughout is not known, but in the area examined by the author the granite has a remarkable overall sameness (ignoring purely local features such as variations in biotite content). Specimens from Junee and Wagga Wagga can be readily matched with others from Wantabadgery. Lithologically similar material was recorded by Raggatt (1933) from Junee Reefs and Sebastopol.

Plate v of Part I of these Studies (Vallance, 1953*a*) indicates that the Wantabadgery granite covers a large area north of the Murrumbidgee River in the Oura–Wantabadgery district and passes across the river near Tenandra. South of Tenandra it forms a prolongation parallel to the strike of the country rocks and occupies the valley of lower Yaven (or Hillas) Creek. South-west of Oura the granite again crosses the river and forms the low ridge on which Kiambeth Trig. Station is situated. Similar granite occurs on the eastern side of Willan's Hill near the city of Wagga Wagga. Although a large part of the granite-metasediment contact appears to transgress the regional strike, detailed work has shown that, in the vicinity of the contact, the strike of the metasediments is deflected sympathetically with the granite. Near its margin the granite tends to have a more gneissic appearance than elsewhere and the foliation typically follows the trend of the margin.

The metasediments near the Wantabadgery granite belong, as a rule, to the knotted schist zone (Vallance, 1953*a*). High-grade rocks are normally confined to within a few feet of the contact; they are, however, more extensive just north of Yaven Trig. Station. Contrasted with this is the wide high-grade zone near the other member of this group, the Green Hills granite.

Like the Wantabadgery granite, the lithologically similar Green Hills granite mapped during the course of this work occupies only a portion (the northern portion) of a large batholith of rather uncertain dimensions. The Green Hills mass has an interesting prolongation to the north-west (cf. the south-east end of the Wantabadgery mass) and has been traced along the upper Yaven Creek and upper Oberne Creek valleys and through the Green Hills Forest to the main Batlow–Tumbarumba road, where it appears just south of Batlow. Except where interrupted by Tertiary basalt near Laurel Hill, the granite can be followed to Tumbarumba. During a hasty reconnaissance south of Tumbarumba, what appeared to be the same granite was followed as far as Tooma and Welaregang and was seen to occur across the Murray River in Victoria. From observations made on the Victorian side of the river it would seem that this granite is at least partly responsible for the large bulk of the Corryong batholith (Edwards and Easton, 1937). To the west of Tumbarumba there is reason to believe that the granite margin is faulted. The granite seems to be identical with, and may be continuous with, the rock called by Mr. L. Hall, of the N.S.W. Geological Survey, the New Maragle granite, which occurs to the east of Tumbarumba. North of Batlow the Green Hills granite is apparently separated from the "basic belt" (Vallance, 1953*b*) by a somewhat gneissic granite belonging to our second group.

This large mass has thus been traced for nearly 50 miles along the regional strike of the country rocks but lack of data on the location of the eastern margin south of Batlow precludes any reliable estimate of its maximum width. Mr. K. R. Sharp has found similar granite on and east of the Tumut River near the S.M.H.E.A.'s Tumut Pond Power Station site. This occurrence is conceivably continuous with the Green Hills or New Maragle granites but the intervening country has not been examined because of its inaccessibility.

In addition to the lithologically comparable Cooma gneiss (Browne, 1914; Joplin, 1942) at Cooma, similar granites have been found on the Murray River, south-west of Mt. Kosciusko (Browne et al., 1946), at Albury (Joplin, 1947), and in parts of north-eastern Victoria (Howitt, 1888; Tattam, 1929).

At Hugel Trig. Station a patch of high-grade metasediments occurs on top of the granite. A similar, and larger, patch is to be found in the Nurenmerenmong Range, east of Tumbarumba. The elevation of these patches above the surrounding granite country suggests that they are remnants of the original roof now isolated by erosion. By way of contrast it might be mentioned that no such remnants have been found in the Wantabadgery mass, although it, like the Green Hills granite, contains many included fragments of the country rocks. The boundary between the granite and the highly metamorphosed sediments of the roof patches is usually rather vague. Similar gradational contacts occur betwen the Green Hills granite and the high-grade country rocks along its western margin; this is particularly true of the contact north of Bago Trig. Station. In contrast to this, the contacts around the Wantabadgery granite are less diffuse (except near Yaven Trig. Station), although here, too, it is difficult to locate exactly the granite-metasediment junction.

The granites of both masses may display a slight, steeply dipping, foliation but they are often fairly massive (cf. Joplin's (1942, p. 186) remarks on the Cooma gneiss). As at Cooma, the foliation in these rocks is usually indicated by trails of biotitic schlieren or by the rarer sub-parallelism of included rock fragments. The foliation, in general, follows the regional trend of the country rocks except where the granite contacts cut across this direction; there the foliation is locally parallel to the margins of the mass. Away from the margins the foliation resumes its regional trend.

Aplitic, pegmatitic, and milky quartz dykes and veins are often associated with these granites, particularly near their margins. A remarkably large quartz dyke forms the Rocky Knob at Oura. Dykes of doleritic and bostonitic rocks have also been found in the granites.

Pegmatites and Aplites.

The pegmatites, often with graphic texture, show few unusual features. In addition to the abundant quartz and K-felspar (orthoclase or microperthite) they usually carry tourmaline, muscovite, and a little acid oligoclase. The tourmaline crystals (up to two inches long) are often fractured across their length and the breaks are typically healed by granular quartz. The pegmatite dykes sometimes have a marginal graphic zone bordering an inner zone, rich in felspar, itself flanking a central region composed largely of quartz and tourmaline (cf. Joplin, 1942, p. 187).

The aplites are fine- to medium-grained rocks with obvious quartz, felspar, and muscovite. Acid oligoclase may be important in addition to the K-felspar. Myrmekitic intergrowths have been observed and small flakes of colourless mica may also replace the felspar. Tourmaline is not as abundant as in the pegmatites. The formation of tourmaline here seems in many cases to have post-dated the crushing which some of these aplites suffered. Pinkish garnet has been found in a few dykes near Oura. The grains (up to 2 mm. across and often rich in quartz inclusions) display rough crystal outlines with slight alteration to chlorite along cracks. There are few signs of much reaction between the aplite material and the garnets, and the origin of the latter is somewhat puzzling. At Albury, oligoclase granites, rather similar to the rocks here grouped with the aplites, also contain garnet (Joplin, 1947); it is believed to be pyrogenic. The garnet in the Oura district has not been analysed but one garnet-bearing rock so studied contains little manganese (Table 2, no. 6). This suggests, though it does not prove, that the garnet is not spessartine-rich. In general, garnets occurring as stable phases in such acid rocks tend to be manganiferous because Mn^{++} does not replace Fe^{++} or Mg^{++} in biotite from granites and pegmatites (Ramberg, 1945) and thus the expected reaction

$$\underset{\text{garnet}}{(FeMg)_3Al_2Si_3O_{12}} + \underset{\text{K-felspar}}{2KAlSi_3O_8} + 2H_2O \rightarrow \underset{\text{biotite}}{K(FeMg)_3AlSi_3O_{10}(OH)_2} + \underset{\text{muscovite}}{KAl_3Si_3O_{10}(OH)_2} + 3SiO_2$$

may not take place if the garnet is rich in manganese. Where almandine occurs in aplitic rocks with sufficient K_2O (e.g. see Sugi, 1930) it often shows some signs of conversion to biotite. Spessartine-rich garnets may in many cases be pyrogenic but almandines occurring in similar acid rocks are perhaps more often xenocrystal. In view of the low MnO in the rock, which had sufficient K_2O to form free K-felspar, it seems somewhat doubtful whether the garnet is pyrogenic in this case. There is, however, no apparent source for the mineral if it is to be regarded as xenocrystal and no clear reason why it should not have reacted more extensively with its environment.

Granite-Granodiorite.

The largest parts of the Wantabadgery and Green Hills masses are composed of rocks which fall into this category. In both masses the rocks outcrop as large boulders and tors which, despite their resistant appearance, are typically very extensively weathered. When fresh the rock is distinctly greyish. In places it may be porphyritic, as a rule the most porphyritic parts being associated with patchy, biotite-rich phases of the granite. Often, however, the rocks have a fairly even, medium-grain size.

TABLE 1

Modes of Plutonic Rocks and of a Basic Patch.

	1	2	3
Quartz	34·6	33·3	22·2
K-felspar	30·4	5·5	1·6
Plagioclase	12·6	38·7	24·4
Biotite	8·9	20·4	42·3
Hornblende	abs.	abs.	abs.
Muscovite (+sericite)	13·3	1·6	8·4
Accessories	0·2	0·4	1·0

1. Biotite granite (sericite-rich). Por. 235, Par. of Oura, Co. Clarendon. (For analysis see Table 2, no. 1.)
2. Granodiorite. Quarry, north-eastern side of Willan's Hill, Wagga Wagga. (For analysis see Table 2, no. 3.)
3. Biotite-rich patch in the Wantabadgery mass near Tenandra Trig. Station. (For analysis see Table 2, no. 5.)

Modes of two of these rocks are given in Table 1. Quartz, felspar, and biotite, with some muscovite, are the chief constituents. Quartz is abundant and normally occurs as irregular grains often faintly dusted with small inclusions. Minute needles of rutile and sillimanite have been noted in the quartz, the sillimanite occurring most commonly near the remnants of metasediment inclusions. Locally, the quartz may show intense strain features.

K-felspar appears mainly as orthoclase or microperthite and may or may not exceed plagioclase in abundance (cf. columns 1 and 2 in Table 1). Some of the felspar has microclinic gridiron-twinning, a feature commonest in the granite near biotite-rich broken-down metasediment relics. The K-felspar may form either euhedral phenocrysts or anhedral grains. Phenocrysts up to one inch long often have good Carlsbad twinning and, sometimes, marginal zones of biotite inclusions. The large felspars are commonly microperthitic with needles and rods of intergrown albite. Similar large felspars may also be developed in the metasediment inclusions. Some of the K-felspar in the granite is myrmekitized; this is another feature which tends to become more obvious near the disrupted inclusions (see Plate xii, A). Muscovite often is abundant near the myrmekite indicating, perhaps, the destination of some of the released potash.

Plagioclase may also occur as phenocrysts or smaller anhedral grains. As at Cooma (Joplin, 1942), it has been found impracticable to distinguish between the relatively plagioclase-rich and plagioclase-poor types in the field. The plagioclase is usually an oligoclase or acid andesine (Ab_{65-70}) and even in the most basic (biotite-rich) phases of the rocks it does not become much more calcic. Some of the plagioclase is roughly zoned and where the mineral has been fractured and healed by later crystallization the zones have an irregular distribution. Parts of certain zoned grains have been completely separated before the final consolidation. Twinning is typical and among the twin-varieties recorded is a rather large group of laws included by Gorai